July 1974

U S D A FOREST SERVICE
RESEARCH NOTE RM - 267

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Using Aerial Measurements of Forest Overstory and Topography to Estimate Peak Snowpack

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On sites where slope steepness and aspect vary widely and several forest overstory size and density classes are intermixed, only topographic attributes need be measured. All of the tested photo scales (1:3,000; 1:6,000; 1:15,840) were satisfactory. On nearly level sites where size and density classes are homogeneous, forest overstory attributes also must be measured, and the 1:15,840 scale is best.

Keywords: Snow survey, aerial photography, *Pinus ponderosa*.

Although the quantity of water flowing from upland watersheds varies considerably from year to year, demand normally exceeds supply in the Southwest. To satisfy demands will require more intensive upland watershed management. This in turn will require new inventory techniques for determining quantity and distribution of water held in snowpacks under forest stands (Warskow 1971). Reservoir managers, although concerned with maximizing stored water at the end of spring runoff, must not allow reservoirs to become full too soon and create a flood hazard.

Direct inventories of snowpack water equivalent on large basins are currently uneconomical (Warskow 1971). An alternative may be to estimate snowpack water equivalent indirectly from measurements of forest overstory and topography obtained from aerial photos. As a first step in this direction, this exploratory study[2] was designed to empirically identify what relationships exist between peak snowpack water equivalent measured on the ground in ponderosa pine stands of Arizona and forest overstory and topography attributes measured on aerial photos. Peak water equivalent may be a key indexing criterion to estimate potential snowpack water yield from a basin (Ffolliott and Thorud 1972). Hopefully, results from this study may subsequently lead to syntheses of inventory systems for indirectly estimating snowpack conditions on large basins.

Study Areas

Data were obtained on the Beaver Creek watershed, located on the Coconino National Forest, and on the Apache National Forest near the Campbell Blue drainage.

Ponderosa pine comprises over 85 percent of the forest cover on the Beaver Creek study area, with an intermingling of Gambel oak (*Quercus gambelii* Nutt.) and alligator juniper (*Juniperus deppeana* Steud.). Timber was last cut prior to 1950, when half of the merchantable sawtimber was removed. Current sawtimber volume averages 2,000 ft^3 per acre. Site index (Meyer 1961) ranges from 60 to 70 ft.

Topography on Beaver Creek varies from essentially level to slopes exceeding 45 percent. Elevation ranges from 7,300 to 7,700 ft. Soils, derived from volcanics, are classified into the Brolliar and Siesta-Sponseller soil management areas (Williams and Anderson 1967). Annual

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[2]This study was supported in part by funds provided by the U.S. Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379.

precipitation averages 24 inches, half of which occurs between November 15 and April 15.

Ponderosa pine comprises over 95 percent of the forest cover on the Campbell Blue study area, with Gambel oak and quaking aspen (*Populus tremuloides* Michx.) intermingled. Timber was last cut in 1966-67, when an estimated 40 percent of the merchantable sawtimber was harvested. Sawtimber currently averages 1,650 ft^3 per acre. Site index (Meyer 1961) varies from 55 to 70 ft.

Gently rolling topography with few slopes exceeding 15 percent characterize Campbell Blue. The mean elevation is 8,010 ft, with a range of 100 ft. Soils are derived from volcanics. Annual precipitation at Alpine, Arizona, 7 miles north, is about 22 inches, almost half of which occurs between October 1 and May 31.

Methods

Three photo flights were made over Beaver Creek (fig. 1) to obtain photo scales of 1:3,000, 1:6,000, and 1:15,840. Two photo flights were made over Campbell Blue to obtain photo scales of 1:6,000 and 1:15,840. A Zeiss[3] aerial photo camera was used with a focal length of 8-1/4 inches. Kodak Plus X Panchromatic film was exposed through a minus blue filter at 1/500 of a second at stop f-8.

On Beaver Creek, a 9-dot-per-square-inch grid was overlaid on 1:15,840 photos, which were stratified by forest crown cover, aspect, and slope percent (Larson et al. 1971). One grid point was picked at random from each stratum, and a cluster of three sample plots was located around that point. Seventy-five plots were located.

On Campbell Blue, 40 individual sample plots were initially located on the ground, and subsequently identified on the photos. The plots were established on sites representative of the forest cover, as judged from the ground. Each plot characterized a homogeneous timber size class and density.

Center points of all sample plots were pinpointed on aerial photos for each scale. Forest overstory and topographic characteristics were then estimated[4] on 1/5-acre circular plots centered over each plot. Average total height of the dominant stand was determined from parallax wedge measurements, and total crown cover percent was determined by comparing photo images with a crown density scale. Topographic measurements included aspect to the nearest 45° and slope steepness to the nearest 5 percent. Aspect and slope steepness were determined from scale line orientation and parallax measurements (Moessner 1964).

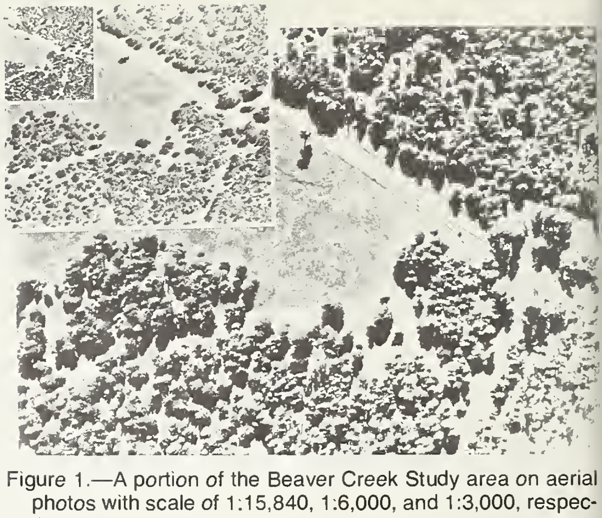

Figure 1.—A portion of the Beaver Creek Study area on aerial photos with scale of 1:15,840, 1:6,000, and 1:3,000, respectively.

The internal sample plot design, on both study areas, consisted of five permanent measurement points arranged in a diamond-shaped pattern within a circular 1/5-acre plot.

Total snow depth and water equivalent were measured with a Federal snow sampler and scale (fig. 2) at each measurement point on both study areas to characterize the snowpack through the season (table 1). Data were obtained during the winters of 1967-68 and 1968-69 on Beaver Creek and during the winters of 1968-69 and 1972-73 on Campbell Blue.

Weather Events

Distribution of 1967-68 winter precipitation was atypical on Beaver Creek, primarily as a result of record snowfall in December (Enz 1968). Approximately 95 inches of snow containing over 10 inches of water fell in a 1-week period. Little wind accompanied this storm, and snow distribution was uniform. Thereafter,

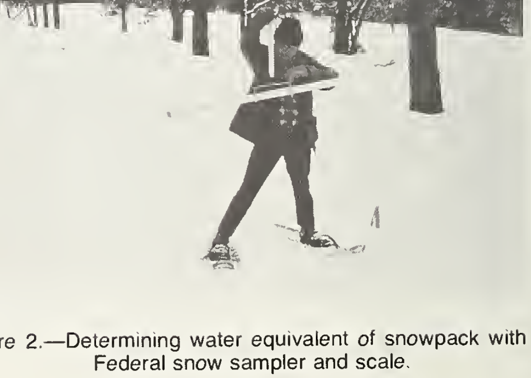

Figure 2.—Determining water equivalent of snowpack with a Federal snow sampler and scale.

[3]Trade and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture.

[4]Photo estimates were made by Karl E. Moessner.

Table 1.--Summary of snowpack characteristics on warm and cool sites

Plots and dates		Precipitation increments[1]	Average snowpack, water equivalent	
			Warm sites	Cool sites
		Inches	- *Inches* -	
BEAVER CREEK PLOTS:				
1968--				
January	7	9.6	8.5	9.0
	20	.1	8.1	8.9
February	10	2.5	8.8	9.3
	24	2.4	8.3	10.3
March	9	.1	5.3	7.8
	30	2.4	1.5	3.9
April	27	1.7	.1	.4
1969--				
February	22	13.5	5.4	7.3
March	8	3.5	7.6	9.4
	15	2.3	9.4	11.1
	29	.3	5.2	8.3
April	12	.1	.3	1.6
May	2	.5	0	.1
CAMPBELL BLUE PLOTS:				
1969--				
January	1	1.9	1.8	2.3
February	22	4.0	1.6	2.5
March	8	1.0	1.5	2.5
	15	.7	1.9	3.0
1973--				
January	27	5.7	1.4	1.9
February	18	3.1	3.4	3.6
March	17	2.9	3.8	5.6

[1] Includes rain and snow, measured in unshielded standard gages.

storms depositing 0.1 to 2.5 inches of water occurred at intervals of 6 to 15 days, yielding a total winter precipitation of 18.8 inches. Maximum air temperatures ranged from 45° to 60° F between storms. Peak snowpack water equivalent was measured on February 10.

Distribution of 1968-69 winter precipitation was more typical on Beaver Creek, although warm weather prevailed throughout December and January. The first measurable snow fell in mid-February. Several storms depositing 0.4 to 1.6 inches of water occurred in late February and early March. Maximum air temperatures between storms ranged from 36° to 48° F. A warming trend followed the last winter storm, with daily air temperatures from 50° to 64° F. Peak water equivalent accumulation was measured following a storm on March 14. Total winter precipitation was 20.2 inches.

The timing of weather events at Campbell Blue was similar to Beaver Creek during the winter of 1968-69. However, only 7.6 inches of winter precipitation was recorded. Peak water equivalent was measured on March 15.

In 1972-73, the first measurable snow fell on Campbell Blue in early November, depositing 0.4 inch of water. Thereafter, storms depositing 0.1 to 1.9 inches of water occurred at intervals of 5 to 14 days. Peak water equivalent was measured on March 17. Total winter precipitation was 11.4 inches.

Results

Peak snowpack accumulation of water equivalent, expressed as a percent of the maximum peak accumulation measured on the study area, was estimated from aerial photos on the basis of: (1) slope steepness and aspect expressed as potential direct beam insolation (Frank and Lee 1966); and (2) crown cover and height of the dominant stand measured on aerial photos and expressed as a single forest cover variable (crown cover x height). Expressing estimated peak snowpack water equivalent as a percent of the maximum measured peak provides a basis for estimating conditions on each sample plot independent of the annual precipitation.

Water equivalent reached a peak 2 weeks earlier on warm aspects (SE, S, SW, and W) than on cool aspects (NW, N, NE, and E) on the Beaver Creek study area during the winter of 1967-68 (table 1). However, for all plots the average peak accumulation occurred on February 10, and a t-test for the two dates by aspect showed no significant difference.

Of all independent variables tested on both study areas, the combination of slope steepness and aspect was most significant. Slope and aspect measurements were converted to potential insolation (Frank and Lee 1966) received on an index date that represented the measurement period. The index date was February 20 in 1967-68, and March 21 in 1968-69 and in 1972-73. All regressions using potential insolation as the only independent variable were significant ($\alpha = 0.05$) in predicting percent of peak water equivalent.

The addition of the forest overstory variable in regressions developed for Beaver Creek increased the accountable variation by only 4 percent. The randomly selected sample plots resulted in the measurement of forest stands with several size classes and densities intermixed, which may have obscured the effect of forest overstory. Furthermore, the wide range (0 to 45 percent) in slope-steepness classes and the number of sample plots in all aspect classes created diverse potential insolation values, possibly overshadowing the influence of forest overstory.

Since all measurements of slope steepness and aspect were similar for all photo scales (Larson et al. 1971), only one equation is needed to predict snowpack condition for each year of study on the Beaver Creek plots:

Water year	Intercept b_0	Slope coefficient b_1	Correlation coefficient	$S_{y \cdot x}$
1967-68	114.6	-0.0692	0.51	11.4
1968-69	125.9	-.0788	.46	11.9

$Y = b_0 + b_1 x_1$

where

Y = percent of peak snowpack water equivalent.

x_1 = potential insolation on index date (Feb.20 for 1967-68; Mar.21, 1968-69) in langleys (Frank and Lee 1966).

$S_{y \cdot x}$ = Standard error about regressions in percent of peak snowpack water equivalent.

Potential insolation was also important on Campbell Blue, but since the maximum slope steepness class was only 15 percent, the range of potential insolation values was reduced. The forest overstory variable was a significant addition on Campbell Blue, possibly because sample plots were chosen for homogeneity of timber size classes and densities. The addition of this variable to the equations increased the accountable variation measured on 1:15,840 photos by a greater amount than on larger scale photos. Thus, only the equation based on 1:15,840 photos is presented for each year of study on the Campbell Blue plots:

Water year	Intercept b_0	Slope coefficients b_1	b_2	Correlation coefficient	$S_{y \cdot x}$
1968-69	287	-0.257	-20.3	0.70	17.4
1972-73	255	-.223	-12.2	.63	15.4

$Y = b_0 + b_1 x_1 + b_2 x_2$

where

Y = percent of peak snowpack water equivalent.

x_1 = potential insolation on index date (Mar.21) in langleys (Frank and Lee 1966).

x_2 = common logarithm of forest crown cover in percent times the average total height of the dominant stand in feet.

$S_{y \cdot x}$ = standard error about regression in percent of peak snowpack water equivalent.

Conclusions

1. It is possible to relate peak snowpack water equivalent measured on the ground to forest overstory and topography attributes measured on aerial photos.
2. On sites where slope steepness and aspect vary widely and several forest overstory size and density classes are intermixed (as on Beaver Creek), only topographic attributes need be measured, and any of the tested photo scales may be utilized. However, on nearly level sites where forest overstory size and density classes are homogeneous (as on Campbell Blue), forest overstory attributes must also be measured. The 1:15,840 photo scale was empirically better for these measurements.
3. Prior to synthesizing an operational inventory system for indirectly estimating snowpack conditions on large basins, it will be necessary to further assess relationships such as developed in this exploratory study in terms of yearly climatic variability. Also, the applicability of such relationships must be extended to represent conditions basin-wide.

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